

# INDIRECT SEARCH FOR DARK MATTER WITH AMS IN POSITRONS, GAMMA AND ANTIPROTONS CHANNELS

D. CASADEI

*INFN, Sezione di Bologna, Via Irnerio 46, 40126 Bologna, Italy*

*E-mail: Diego.Casadei@bo.infn.it*

The Alpha Magnetic Spectrometer (AMS), to be installed on the International Space Station, will provide data on cosmic radiations in a large energy range. The main physics goals in the astroparticle domain are the antimatter and the dark matter searches. Dark matter should be composed of non baryonic weakly interacting massive particles, a good candidate being the lightest SUSY particle in R-parity conserving models. As a prototype for the AMS-02 experiment, the AMS-01 particle spectrometer was flown on the Space Shuttle Discovery in near earth orbit for a ten day mission in June 1998. The direct identification of positrons in AMS-01 was limited to energies below 3 GeV due to the vast proton background and the characteristics of the subdetectors, but the sensitivity towards higher energies (up to 40 GeV) was extended by identifying positrons through the conversion of bremsstrahlung photons. AMS-02 will greatly improve the accuracy on the positron spectrum, which will be measured up to 300 GeV, together with the antiproton and  $\gamma$ -ray flux, thus providing a unique chance to measure all relevant neutralino decay channels with the same experiment.

*Keywords:* Dark Matter; Cosmic Rays; Neutralino annihilation; AMS experiment

## 1. The AMS experiment

The Alpha Magnetic Spectrometer (AMS) is a large-acceptance ( $0.4 \text{ m}^2 \text{ sr}$ ) space experiment to be operated for at least 3 years on board of the International Space Station <sup>1</sup>, whose main goals are the search for cosmic antimatter, for the signatures of the dark matter, for exotic particles (like strangelets or heavy leptons), and the precise measurement of cosmic ray (CR) rigidity spectra from about 0.2 GV up to 2 TV. The AMS international collaboration developed a first version of the magnetic spectrometer (AMS-01) which was flown on board of the space shuttle Discovery for a 10 days mission on June 1998 (NASA STS-91 flight), and is currently assembling an upgraded version of the detector (AMS-02).

The AMS-01 space spectrometer <sup>1</sup> (figure 1) is based on a permanent Ne-Fe-B magnet (dipolar field, 0.13 T maximum intensity) enclosing 6 planes of double-sided silicon tracker and the anticoincidence system (ACC), consisting of 16 plastic scintil-

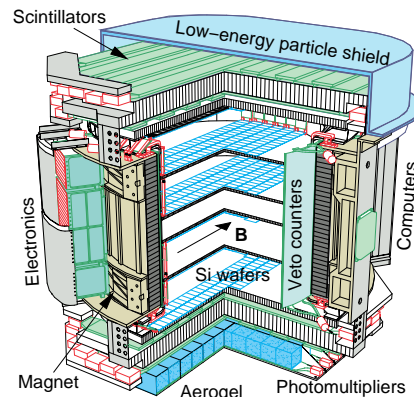


Fig. 1. The AMS-01 detector.

lator paddles. Above and below the magnet, two couples of scintillator planes consisting of 14 counters each provide the measurement of the time of flight (TOF) and an aerogel threshold Čerenkov counter (ATC) placed below the magnet is used to improve the separation between positrons and protons.

The AMS-02 detector <sup>2</sup> is based on a superconducting magnet (0.85 T maxi-

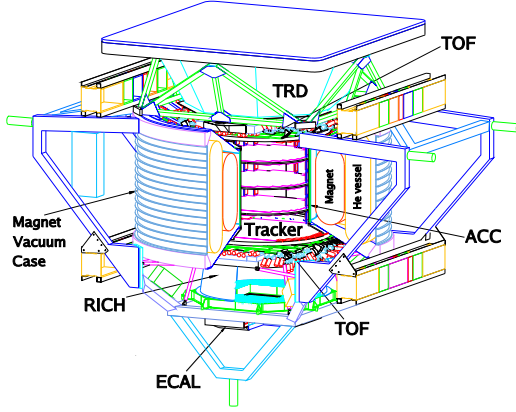


Fig. 2. The AMS-02 detector.

imum intensity) enclosing the ACC system and 8 layers of double-sided Si tracking planes with improved spatial resolution. In addition, a proximity-focusing ring-imaging Čerenkov detector (RICH) replaces the ATC, a transition-radiation detector (TRD) is positioned above the upper TOF planes and an electromagnetic calorimeter (ECAL) is installed on the opposite side (figure 2). With the help of the stronger magnetic field and the better tracking, the maximum detectable rigidity moves from about 0.2 TV to 2 TV, whereas the momentum resolution goes from 5% to 2% in the range where the CR flux is maximum.

Figure 3 shows the CR spectra of protons, He nuclei, electrons and positrons measured by AMS-01 in June 1998<sup>3,4,5,6</sup>. The direct measurement of the positron spectrum is limited by the high proton background (whose flux is  $\sim 10^4$  higher than positrons), which is suppressed with the help of the ATC only below the Čerenkov threshold (3 GeV). At higher energy, a different way has to be followed to suppress the background of a factor  $\sim 10^{-6}$ : a recent reanalysis of AMS-01 data<sup>6</sup> focused on the rare events in which the primary electron or positron emitted a bremsstrahlung photon which converted into a  $e^+e^-$  pair (resulting in 3 almost coplanar tracks). This has made possible to extend

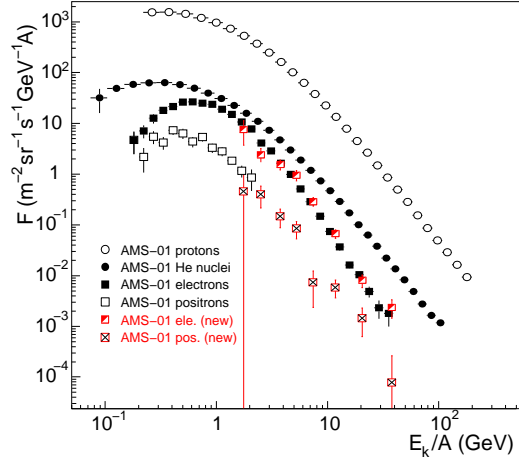


Fig. 3. Primary CR spectra measured by AMS-01.

the energy range up to 40 GeV.

In addition to the measurement of the primary CR spectra, AMS-01 also studied secondary particles, created by the interaction of CR in the Earth atmosphere. A backtracing algorithm was used to follow all particles with energy below the geomagnetic cut-off to see if they had originated in the atmosphere. It was found that the trapped particles may have short life before being absorbed again in the atmosphere, or a relatively long life (longer than 1 s) when bouncing back and forth between two mirror points. AMS-01 found that this is true for electrons and positrons<sup>4</sup>, protons<sup>7</sup>, and helium<sup>5</sup>.

## 2. Dark Matter

When looking at the universe at large scales, several independent measurements of the matter distribution (SDSS), of galactic and QSO red-shifts (2dF), of the CMB spectrum (COBE, Boomerang, MAXIMA, WMAP) all agree on two important cosmological features. First, the universe is spatially flat, as a consequence of the extraordinary expansion phase (“inflation”) which took part in the very early stages of the cosmic evolution. Second, the universe dynamics are

today vacuum dominated: we are living in a phase when the accelerated cosmic expansion can be described as the effect of the “cosmological constant”  $\Lambda$  of Einstein’s equations, which is responsible of about 74% of the total energy density in the universe <sup>8</sup>.

Though the energy density due to the matter content of the universe is quite high (about 26%), a number of observations (galaxy rotation curves, baryon to photon ratio, light element abundances) put severe constraints on the amount of baryons in the universe: they cannot constitute more than a few percent of the total energy density <sup>9</sup>. The biggest fraction of the matter is visible only thanks to its gravitational effects: it must be consisting of neutral objects, hence the name of “dark matter” (DM). In addition, DM particles must have been not relativistic when leaving the radiation dominated epoch, to be consistent with the power spectrum of the CMB and with the galaxy formation, hence they are heavy. Finally, beyond gravity, they may have only weak interactions, hence the WIMP acronym (weakly interacting massive particles).

Among the DM candidates (for example axions <sup>10</sup>, heavy leptons <sup>11</sup>, sterile neutrinos <sup>12</sup>), the lightest supersymmetric (SUSY) particles are the preferred option <sup>13</sup>. WIMPs may be a mixture of the neutral SUSY weak-interaction eigenstates (photino, wino and two higgsinos), the neutralinos  $\chi$ , whose mass  $m_\chi$  is expected to be between several tens of GeV and few TeV. The conservation of R-parity implies that neutralinos and antineutralinos are stable. In addition, in the simplest SUSY models they are Majorana particles, i.e. they are their own antiparticles. Annihilations would produce fermion-antifermion pairs (heavy fermions being strongly favored) or gauge bosons, whose end products are stable particles: high-energy photons, electrons and positrons, protons and antiprotons. Hence, we might be able to detect the

annihilation signatures looking at the spectra of such particles.

The annihilation rate is  $\Gamma = \langle \sigma v \rangle$ , where  $\langle \sigma v \rangle$  is the thermally averaged total cross section for annihilation times the relative velocity  $v$ , which is very small: annihilations can be considered practically at rest. Neutralinos ceased to be in thermal equilibrium with the other particles when  $\Gamma < H$ , the expansion rate of the universe: at this point the annihilations were exponentially suppressed and a relic cosmological abundance remained <sup>13</sup>. The current neutralino energy density, in units of the critical density  $\rho_c = 1.05 \times 10^{-5} h^2$  (where  $h$  is the Hubble parameter in units of  $100 \text{ km s}^{-1} \text{ Mpc}^{-1}$ ), is <sup>13</sup>:

$$\Omega_\chi h^2 = \frac{m_\chi n_\chi}{\rho_c} \simeq \frac{3 \times 10^{-27} \text{ cm}^3 \text{ s}^{-1}}{\langle \sigma v \rangle} \quad (1)$$

(independent from the mass  $m_\chi$  apart from logarithmic corrections).

A recent analysis of EGRET data <sup>14</sup> has shown that the diffuse high-energy gamma-ray spectrum is consistent with a model of galactic CR propagation in which the annihilations of neutralinos with mass  $m_\chi = 50\text{--}100$  GeV is considered. This result has been debated <sup>15</sup>, because the same model seems to overproduce antiprotons and requires a peculiar DM distribution for our Galaxy. To obtain convincing results, we must observe the effects of WIMPs annihilations in all decay channels. The best ones are the antiprotons and positrons at high energy, because proton and electron spectra are dominated by the ordinary cosmic rays. In particular, one would expect some excess in the positron/electron and antiproton/proton ratios around the mass of the neutralinos.

### 3. AMS sensitivity to DM signatures

Though the positron fraction measured by AMS and HEAT (figure 4, from ref.<sup>6</sup>) shows

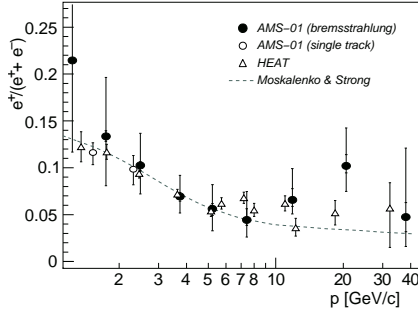


Fig. 4. Positron fraction measured by AMS-01 and HEAT.

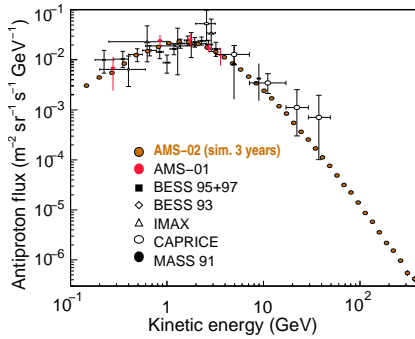


Fig. 5. Antiproton flux. Expected results from AMS-02 are shown together with existing measurements.

a possible excess at high energy with respect to the ordinary CR component (dashed line <sup>16</sup>), still no conclusive evidence has been found about the possibility that neutralino annihilations really contribute to the observed spectra. In particular, the high energy part of the antiproton spectrum is still uncovered (figure 5).

The AMS-02 detector will be able to accurately measure the spectrum of protons, antiprotons, electrons, positrons and  $\gamma$ -rays up to 300 GeV: a unique possibility to measure all relevant decay channels with the same experiment. Figure 6 shows the AMS-02 angular resolution (top panel) and energy resolution (bottom panel) for  $\gamma$ -rays <sup>17</sup>. Figure 5 shows the expectation after 3 years for the antiproton spectrum, for the null hypothesis (no WIMP annihilation). The sta-

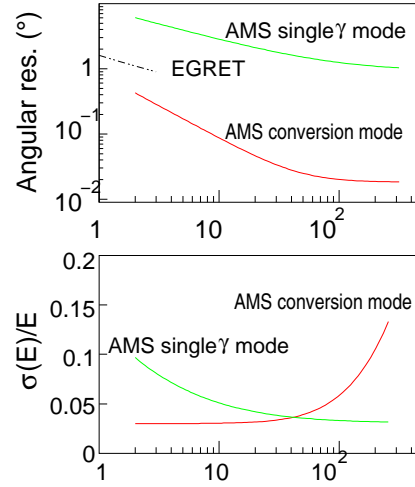


Fig. 6. Gamma-ray sensitivity of AMS-02.

tistical errors are comparable to the symbol size: AMS-02 will be able to check for DM annihilation signatures with unprecedented sensitivity.

## References

1. M. Aguilar et al., Phys. Rep., vol. 366, no. 6 (2002) 331.
2. J. Alcaraz et al., NIM A478 (2002) 119.
3. J. Alcaraz et al., Phys. Lett. B490 (2000) 27.
4. J. Alcaraz et al., Phys. Lett. B484 (2000) 10.
5. J. Alcaraz et al., Phys. Lett. B494 (2000) 193.
6. H. Gast, J. Olzem, S. Schael, arXiv: astro-ph/0605254.
7. J. Alcaraz et al., Phys. Lett. B472 (2000) 215.
8. J.L. Tonry et al., Astrophys. J. 594 (2003) 1.
9. D.N. Spergel et al., arXiv: astro-ph/0603449.
10. P. Sikivie, arXiv: hep-ph/0606014.
11. D. Fargion, M. Khlopov, C.A. Stephan, arXiv: astro-ph/0511789.
12. K. Abazajian, S.M. Koushiappas, Phys.Rev. D74 (2006) 023527.
13. G. Jungman, M. Kamionkowski, K. Griest, Phys. Rep. 267 (1996) 195.
14. W. de Boer et al., arXiv: astro-ph/0508617
15. L. Bergstrom et al., arXiv: astro-ph/0602632
16. I.V. Moskalenko, A.W. Strong, Astrophys. J. 493 (1998) 694.
17. A. Jacholkowska et al., Phys.Rev. D74 (2006) 023518.